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Anaerobic Digestion of Lime Sewage Sludge

Research Report No. 50

arch Program for the Abatement of Municipal Pollution under Provisions of the Canada-Ontario Agreement on Great Lakes Water Quality

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ANAEROBIC DIGESTION OF LIME SEWAGE SLUDGE

by

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RESEARCH PROGRAM FOR THE ABATEMENT
OF MUNICIPAL POLLUTION WITHIN THE
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ABSTRACT

This study, designed to assess the ability of the anaerobic digestion process to accept the sludge produced by the addition of hydrated lime to the raw sewage of a conventional activated sludge plant, was supported under the Canada-Ontario Agreement on Great Lakes Quality.

The study was carried out in conjunction with full-scale phosphorus removal at the Newmarket 2.0 MIGD activated sludge plant. This report covers an intensive sampling program on the two-stage anaerobic digester carried out between March, 1972 and March, 1973.

The study determined that normal digester operation when receiving lime sewage sludge may be anticipated, but that care should be used to eliminate shock loading effects when starting up a digester on lime sewage sludge.

RÉSUMÉ

L'étude réalisée veut évaluer le pouvoir du procédé de digestion anaérobie à transformer les boues résultant de l'addition de chaux hydratée aux eaux résiduaires brutes des usines de traitement traditionnelles à boues activées. Le financement de l'entreprise s'inscrit dans le cadre de l'entente Canada-Ontario sur la qualité de l'eau des Grands lacs.

L'étude s'est effectuée en rapport avec la déphosphoration très poussée qui se pratique à l'usine de traitement à boues activées de Newmarket (débit: 2 millions de gallons par jour). Le présent rapport donne les résultats d'un échantillonnage intensif effectué dans le digesteur anaérobie à deux phases entre mars 1972 et mars 1973.

Les chercheurs ont établi que les boues additionnées de chaux peuvent se digérer normalement, mais qu'il faut, dans ce cas, prévenir les effets des variations brusques de charge en mettant le digesteur en marche.

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1. INTRODUCTION

By the end of 1975 Ontario will have phosphorus removal facilities in operation at more than 200 wastewater treatment plants serving a total of some 4.7 million people. Permanent phosphorus removal facilities were operational in 75% of these plants by the end of 1973.

Certain chemical coagulants have been shown to be compatible with physical settling and biological systems in achieving high phosphorus removal efficiencies. Those chemicals showing most promise include aluminum sulphate, calcium hydroxide and ferric chloride. Certain reservations have been expressed, however, as to the suitability of the anaerobic digestion process of sludge treatment in handling the new chemical sludges.

The first full scale phosphorus removal facility in operation in Ontario was at the Newmarket Water Pollution Control Plant (WPCP). Here hydrated lime is added to the raw sewage of the 2.0 MIGD conventional activated sludge process, effecting an average 80% phosphorus removal efficiency. Sludge treatment is provided by a two-stage anaerobic digester with ultimate disposal onto neighbouring farm fields.

Following the start-up of the phosphorus removal process, problems were experienced in the operation of the digester. After about four months operation, gas production within the digester dropped off to such a level that it had to be opened to permit sludge withdrawal.

Prior to April 1, 1972, the date of initiation of this study, laboratory investigations had indicated that anaerobic digestion of the lime sludge should be possible and the digesters had been placed back into operation on about March 1. By the middle of April, the digester was operating in such a way that gas production was adequate for intermittent use of fuel for the boiler. The activity under this study was directed towards evaluating the operation of the anaerobic digestion process for the treatment of lime sludge.

1.1 Newmarket Phosphorus Removal Process

The Newmarket WPCP is a 2.0 MIGD design conventional activated sludge plant treating the municipal wastewater from a

primarily residential community. Sewage strength is normal, averaging 231 mg/l biochemical oxygen demand (BOD), 437 mg/l suspended solids (SS) and 11.3 mg/l total phosphorus as P.

The phosphorus removal process, consisting of lime storage, feeding and mixing facilities, was installed during the winter of 1970-71, with process start-up in early March, 1971.

Figure 1 presents a line diagram of the entire plant including the phosphorus removal facilities.

Hydrated lime is fed as a slurry at a dosage of 200 mg/l as $Ca(OH)_2$ to the raw sewage flow into the rapid mix tank upstream from the primary clarifiers. This tank provides an eight-minute contact period at design flow, ensuring intimate mixing of the lime with the sewage.

1.2 Anaerobic Digestion Process

Anaerobic digestion is a sludge stabilization process, the principle purposes of which are to make the sludge less odourous and putrescible, to reduce the pathogenic organism content and produce a substantial reduction in the amount of volatile suspended solids.

Sludge digestion is a preliminary stage in the final disposal of the sludge, and is attributed with the following advantages:

a) the process causes no appreciable odour nuisance;

b) the gas produced reduces the quantity of sludge solids for later disposal;

c) the gas can be used as fuel for power production or heating purposes;

d) after digestion it is often possible, by further storage, to separate a portion of liquor from the solids, thus reducing further the volume of liquid sludge for final disposal;

e) the anaerobic digestion process destroys many of the pathogenic organisms contained in raw sludge; and

f) the digested product can be disposed of with very little odour nuisance and is especially suited to land application.

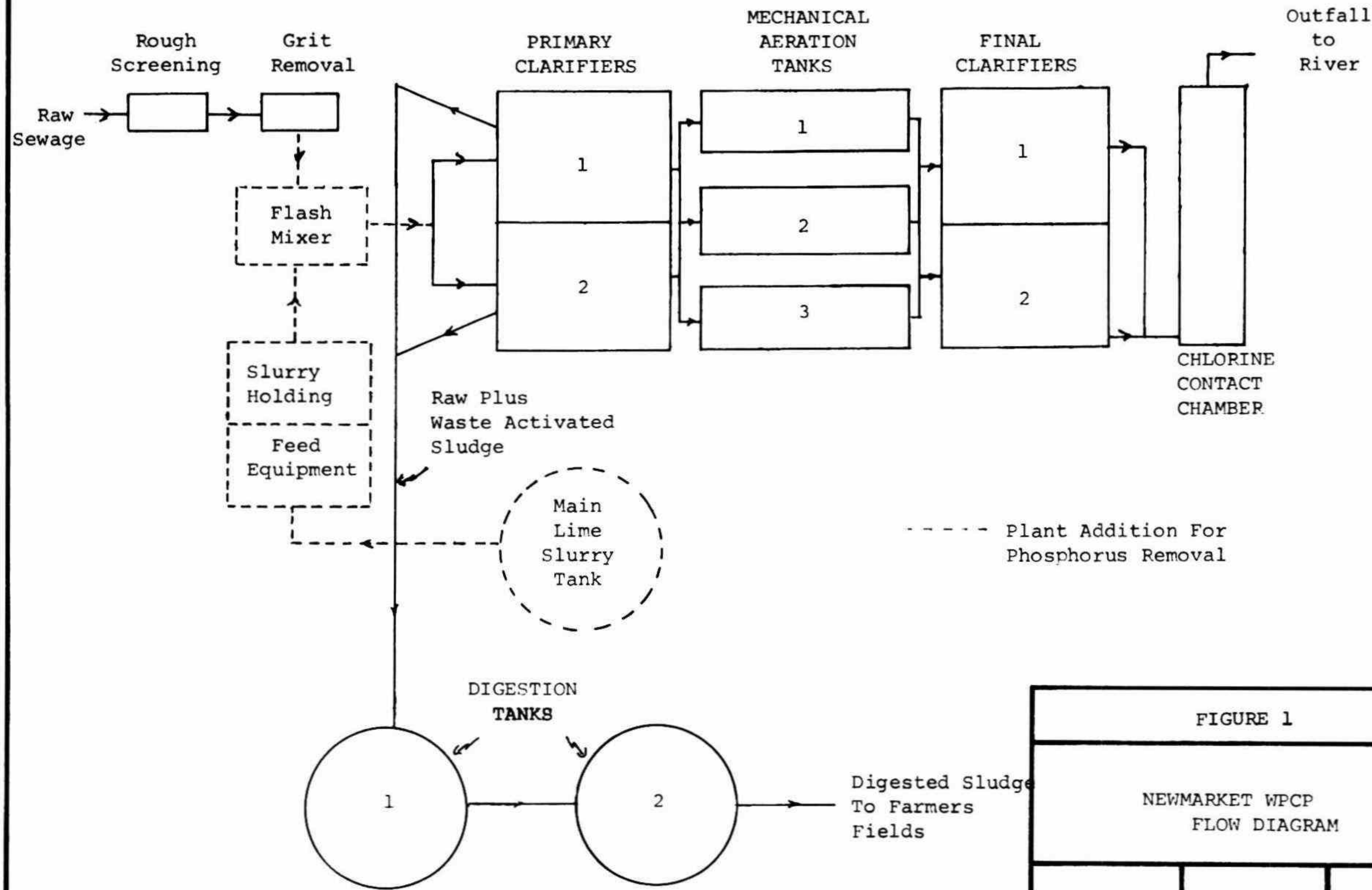

FIGURE 1

NEWMARKET WPCP FLOW DIAGRAM

Digestion is a complex biochemical process in which several groups of anaerobic and facultative organisms simultaneously assimilate and break down organic matter. It is generally considered as a two-stage process in which the two phases are so associated that the first phase end products are utilized by the second phase as rapidly as they are produced according to the following:

$$\text{Complex Organics} \xrightarrow[\text{Phase 1}]{\qquad} \begin{array}{l}\text{Organic Acids}\\ \text{Aldehydes}\\ \text{Alcohols}\\ CO_2\\ H_2\end{array} \xrightarrow[\text{Phase 2}]{\qquad} CO_2 + CH_4$$

In the first phase, acid forming facultative and anaerobic bacteria, by oxidation-reduction reactions, convert complex organics to simpler organic compounds. In this phase little change occurs in the total amount of organic material in the system, although some lowering of pH results. Also in this phase, the alkaline buffering materials are produced.

In the second phase, methane-forming bacteria metabolize the end products of the first phase, producing primarily methane and carbon dioxide. BOD and COD reduction takes place in this second phase with the removal of methane gas from the digester.

The methane-forming organisms are very strict anaerobes, and the anaerobic digestion process is essentially controlled by the second phase. Methane formers grow at a relatively slow rate, and are particularly sensitive to environmental changes such as pH, substrate composition and temperature.

1.3 Design Considerations

The primary requirements for effective sludge digestion are (i) sufficient tank capacity to allow time for the fermentation of organic matter and the growth of methane-producing bacteria; (ii) adequate mixing of the incoming sludge with the active digesting solids, and (iii) maintenance of an optimum temperature within the mesophilic

range, normally about 95°F. Maintenance of a particular temperature is not as important as maintenance of the temperature at a constant value. Since acid formers are able to respond more rapidly to changes in temperature than are the methane bacteria, a temperature change of two to three degrees can be sufficient to disturb the essential dynamic balance between the two phases. The digester must also provide an area for bacterial growth, an area for solids and liquid separation and an area for sludge compaction.

The anaerobic digestion process is designed with a hydraulic retention time of from 30 to 60 days and an organic loading of from 0.02 to 0.1 pounds volatile solids per day per cubic foot (lb VS/day/cu ft). Raw and digested sludge are intermittently fed and withdrawn, respectively.

1.4 Control of the Digestion Process

At present, there is a lack of detailed knowledge concerning the actual processes involved in digestion and consequently also concerning the causes of digester failure. However, over the years "normal" operating parameters have been established and "causes" of digester failure have been documented.

There are five basic laboratory tests which are used to monitor the digester operation. Most of these tests measure conditions which occur after digestion and/or give average information about what is happening during digestion. They are all subject to wide variation within a "normal" operating range, depending upon sludge composition and the environment. The five basic tests used are:

1. Volatile acids concentration gives an indication of the state of the digester. A good indication of digester failure is a rapid increase in volatile acids concentration rather than a high or low value. Normal volatile acids concentrations range between 50 and 500 mg/l as acetic acid.

2. pH control within the favourable range of 6.6 to 7.4 is highly important. Lime is frequently used to increase digester pH.

3. Alkalinity in the form of ammonium bicarbonate (1500 to 5000 mg/l as $CaCO_3$) serves to buffer the digester contents and maintain the pH in a favourable range. A high alkalinity within the digester reduces the adverse effects of pH changes in the raw sludge.

4. Volatile solids destruction is an important indication of the efficiency of the digestion process.

5. Perhaps the best indication of digester failure is a change in composition of digester gas or a drop in its production. The normal composition of digester gas is about 35% carbon dioxide and 65% methane; however, again it is any sudden change in composition which is important.

The digester fails when the biochemical-biological processes involved are upset. In most cases the cause can be traced back to hydraulic or organic overloading, poor digester mixing, or a reduction in digester temperature. Other causes could include the input of toxic industrial wastes, toxic metals and toxic ion concentrations, and rapid changes in raw sludge pH.

2. NEWMARKET DIGESTER SYSTEM

The sludge digestion process at the Newmarket WPCP is a two-stage anaerobic process. The primary digester is a 40-foot diameter by 21.25-foot side wall depth concrete tank of 26,800 cu ft capacity. Gas mixing is provided by a gas compressor recirculating digester gas to the bottom of the tank. The primary digester has a loading rate at design of 0.097 lb volatile solids/cu ft/day.

Secondary digestion takes place in a 40-foot diameter by 23-foot side wall depth concrete tank of 28,950 cu ft capacity. The loading rate at design for the total digestion facility is 0.046 lb VS/cu ft/day.

Raw sludge is fed to the primary digester by one of two 10-inch positive displacement plunger pumps on a timed basis. Digested sludge is withdrawn by means of a centrifugal pump with piping connections such that it may be withdrawn from three different levels within the secondary digester. Digester supernatant flows to the raw sewage wet well.

Heating of the primary digester contents to about $95^{o}F$ is accomplished by recirculating sludge from the primary digester through a heat exchanger and back to the digester. The plant boiler is fueled either by digester gas or fuel oil.

2.1 Digester History Prior to Study

Digester operation prior to lime addition start-up in March, 1971, as indicated by gas production and quality, alkalinity and volatile acids concentration, appeared to be normal and continued so until about the middle of May. Gas quality determinations indicated a CO_2 content of about 23% and a CH_4 content of about 73% and, although no gas measuring equipment was working at the time, the boiler was operating about 60% of the time on digester gas. Volatile acids concentration within the primary digester was relatively constant at about 160 mg/l as acetic acid. From May on, there was a gradual drop in gas production and pressure, until the CO_2 production dropped so low that the pH of the digester contents began to rise. By the end of July, gas production within the digesters had dropped off to such a low rate that a vacuum

was caused when sludge withdrawal was attempted and the digesters had to be opened to permit sludge withdrawal. Digestion failure was, at that time, attributed to the high pH of the sludge feed.

The primary digester was then used as a sludge holding and thickening tank. Sludge was withdrawn from the primary digester for disposal on agricultural lands.

Laboratory studies carried out while the digesters were shut down indicated that the pH of the raw sludge decreased from an initial 10.4 average to a value of 9 to 9.5 in a period of less than two hours while sitting in the beaker. Subsequently, laboratory digestion studies of the lime sludge fed at a pH of 10 indicated the sludge to be digestible.

Modifications were made to the raw sludge pumping cycle, such that raw sludge from one primary clarifier was recycled back to the lime sewage rapid mix tank while sludge was wasted to the digester from the other clarifier. A pumping schedule was maintained such that a $1\frac{1}{2}$- to 2-foot depth of sludge was allowed to build up in the clarifier providing adequate detention such that the pH of the raw sludge entering the digester averaged 9.4, and in early March, 1972, the digesters were recapped and placed back into operation. Thus, at the time of initiation of this study, the digesters were just starting to operate as digesters again.

2.2 Study Outline

The study consisted of monitoring the digester operation during a one-year period from March, 1972 to March, 1973. The data obtained were reviewed for normal digester operation and compared to data collected prior to the initiation of the phosphorus removal process. An attempt was also made to develop a mass balance for the digester operation during the period of study.

Raw and digested sludge volumes were recorded and daily grab samples taken for analyses of total solids, total volatile solids, total Kjeldahl nitrogen, total and soluble phosphorus, alkalinity and pH. Raw sludge volume was computed from the raw sludge pump plunger displacement and revolution counter, while digested sludge volume was

taken as the volume of sludge hauled by tank truck.

Grab samples of digester supernatant were also taken daily and analyzed for total solids, volatile solids, total Kjeldahl nitrogen, total and soluble phosphorus, volatile acids, alkalinity and pH. An attempt was made to measure supernatant volume but no workable means of doing so was found, and so for purposes of mass balance determinations it was taken to be the difference between the raw sludge and digested sludge volumes.

Samples of digester gas were taken weekly and analyzed for CO_2 and CH_4 content. Gas volume measurements were available during the last month of study only.

3. RESULTS AND DISCUSSION

Table 1 presents average values of many of the pertinent digester operational data for 1970 prior to the operation of the phosphorus removal process, and for the period November, 1972, to March, 1973, during which time the digester was operating on lime sludge resulting from lime addition to the raw sewage. The 1970 data have been taken from the 1970 Operating Summary for the Newmarket - E. Gwillimbury WPCP prepared by the Division of Plant Operations, Ontario Water Resources Commission.

This table is presented for comparative purposes only, and no direct correlation between the data for the two periods has been attempted. The raw sewage flow during this study period averaged 1.85 MGD while that for 1970 averaged 1.58 MGD. In addition, the raw sewage suspended solids concentration averaged 198 mg/l during 1970 and 360 mg/l during this study. Thus, a very significant portion of the increase in raw and digested sludge solids for the study period can be attributed to the increased suspended solids loading on the plant.

Perhaps the best indicators of digester operation are volatile solids reduction, gas production and quality and digested sludge characteristics. Quality changes in digester supernatant are also important considerations. Each of these parameters is considered below.

3.1 Volatile Solids Reduction

Normal digester operation will reduce the volatile solids content of raw sludge by anywhere from about 35 to 60%. During this study the volatile solids reduction of the lime sludge averaged 37% based upon mass balance calculations (see Appendix). Considering the very low (27%) volatile solids content of the raw lime sludge, this percent reduction, although somewhat lower than normal, is relatively good.

3.2 Gas Production

3.2.1 Quantity

Gas production by the digestion process is normally measured

TABLE I

DIGESTER OPERATIONAL DATA
PRIOR TO AND DURING LIME ADDITION

	Before Lime Addition (1970 Data)	During Lime Addition (1972-73 data) (200 ppm $Ca(OH_2)$
Raw Sludge		
% Solids	3.4	9.4
% Volatile	62	28
lb solids/MG sewage	1670	4640
gal/MG sewage	4900	5730
Digested Sludge		
% Solids	3.3	10.2
% Volatile	56	24
lb solids/MG sewage	878	3190
cu yd/MG sewage	19.2	24
Digester Supernatant		
% Solids	0.7	1.2
% Volatile	N.D.	24
Sol. P (ppm)	150	4
Primary Digester Loading		
lb VS/cu ft/day	0.06	0.09
Digester Gas		
cu ft/day	N.D.	15000
cu ft/lb VS destroyed	N.D.	32
% CO_2:%CH_4	29:72	24:70
Volatile Solids Reduction		
%	22*	37**

Note: N.D. - Not Determined
* - Using standard equation $\left[\% \text{ Reduction} = 100\left(1 - \frac{\% \text{ Vol}_d \times \% \text{ Ash}_r}{\% \text{ Vol}_r \times \% \text{ Ash}_d}\right)\right]$
** - Based on mass balance

as a function of the reduction in volatile solids within the process. Normal production, based upon Ministry of the Environment, Project Operations Branch operations reports, is in the range of about 10 to 30 cu ft/lb VS destroyed. That for the digestion of lime sludge during the last month of this study averaged 32 cu ft/lb VS destroyed. Thus, digester operation as measured by gas production was at the high end of the normal range.

3.2.2 Quality

The quality of the gas produced by the digestion process is a measure of the completeness of the digestion process. Gas from a well-operating digester will normally contain approximately 25% carbon dioxide and 70% methane. That of the digestion process receiving lime sludge during this study averaged 21% CO_2 and 72% CH_4, indicating production of a good quality gas.

3.3 Digested Sludge Characteristics

As the sludge from the Newmarket WPCP is disposed of by application to cropland, the digested sludge was characterized with this ultimate disposition in mind.

The volatile solids content of the digested sludge is low indicating, perhaps, that odours produced from subsequent decomposition would be minimal as compared to normal digested sludge. The sludge, however, does seem to have a peculiar odour which is quite persistent, even though not as offensive as that of normal sludge.

The pH of the lime sludge is stabilized at about 7.2 during the digestion process. This is perhaps an ideal pH for sludge that is to be applied to agricultural land, as any heavy metals contained in the sludge would tend to increase in solubility at a lower pH. The sludge pH is not high enough, however, to adversely affect the soil.

The digested lime sludge contains about 1.4% of total phosphorus and 1.8% of total nigrogen on a dry weight basis. Preliminary studies have indicated this sludge to be a good source of available nitrogen and phosphorus for crop growth. Crops grown on fields where this sludge has been applied have shown no detrimental, only beneficial, effects from the application.

One significant property was noted concerning the operation of the digestion process during lime addition. The total solids content of the digested sludge varied drastically from load to load, from as low as about 2.5% to as high as about 28%. Using the various draw-off sample lines in the secondary digester, it was found that the solids seemed to stratify at different levels with relatively clear liquid between the levels. No cause of this stratification was determined and no adverse effects of it on digester operation were noted.

3.4 Digester Supernatant Quality

The quality of the supernatant as measured by total solids concentration remained relatively constant throughout the duration of the study. The solids content, however, did increase from 0.7% prior to lime addition to an average of 1.2% during the study. No effects of this increased loading on the primary clarifiers were noted.

Of considerable interest in a phosphorus removal facility is the fact that the soluble phosphorus content of the supernatant was reduced from 150 to 4 ppm.

4. CONCLUSIONS

a. Sludge produced by lime addition to a conventional activated sludge sewage treatment facility may be digested in a two-stage anaerobic digester. Normal digester operation may be expected.

b. When starting up a lime treatment facility, lime addition should be increased to the optimum level in stages of about 50 ppm over a three to four week period. Drastic variations in feed concentration must be avoided.

c. A slight deterioration in digester supernatant with respect to solids content may be expected but a marked reduction in supernatant soluble phosphorus content will result.

d. Digested lime sludge may be disposed of by application to agricultural lands in accordance with approved practices, as the lime itself is not expected to have any detrimental effects on the soil, crops or environment. The lime should actually be quite beneficial in adjusting the pH of acid soils.

APPENDIX

APPENDIX A

DIGESTER MASS BALANCE CALCULATIONS
FOR PERIOD NOVEMBER, 1972 to MARCH, 1973

Raw Sludge Volume	=	2,898,582	gallons
Raw Sludge Total Solids	=	94,000	ppm
	or	2,725,000	lb
Raw Sludge Volatile	=	26,300	ppm
	or	762,300	lb
Digested Sludge Volume	=	1,833,557	gallons
Digested Sludge Total Solids	=	102,000	ppm
	or	1,870,228	lb
Digested Sludge Volatile Solids	=	24,400	ppm
	or	447,400	lb
Digester Supernatant Volume	=	1,065,025	gallons
Digester Supernatant Total Solids	=	12,000	ppm
	or	127,800	lb
Digester Supernatant Volatile Solids	=	2,800	ppm
	or	30,600	lb

(i) Total Solids Loss

= Raw Solids - (Digested Solids + Supernatant Solids)

= 2,725,000 - (1,787,700 + 127,800)

= 727,200 lb

(ii) Volatile Solids Loss

= Raw V.S. - (Digested V.S. + Supernatant V.S.)

= 762,300 - (447,400 + 30,600)

= 284,300 lb

Therefore: Reduction in Volatile Solids $= \frac{284,300}{762,300} \times 100 = 37\%$